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of

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for

WAVELENGTH-DIVISION MULTIPLEXER OR DEMULTIPLEXER USING EXPANDED CORE FIBERS

WAVELENGTH-DIVISION MULTIPLEXER OR DEMULTIPLEXER USING EXPANDED CORE FIBERS

1. **Claim to Priority**

[001] This application claims priority to and the benefit of U.S. Provisional Patent Application No. 60/391,258, filed on June 24, 2002, entitled, "Wavelength Division Multiplexer or Demultiplexer Using Expanded Core Fibers," which is incorporated herein by reference in its entirety.

2. **Governmental Rights**

[002] The invention was made with Government support under Contract No. DASG60-98C-0062, awarded by the U.S. Army and contract No. DASG60-98-0108, also awarded by the U.S. Army. The government has certain rights in the invention.

BACKGROUND OF THE INVENTION

3. **The Field of the Invention**

[003] The present invention generally relates to optics, and more particularly, to a wavelength division multiplexer or demultiplexer using thermally expanded core (TEC) fibers.

4. **Background of the Invention**

[004] The increasing demand for high-speed broadband communications has resulted in a rapid increase in fiber optic communications systems that require faster and more reliable components to interconnect associated optoelectronic devices of a network. One problem encountered with some conventional systems includes inefficient use of the full optical

spectrum for communicating signals and hence data. For example, Figure 1 illustrates two conventional optical fibers having a core of diameter "*a*" surrounded by a cladding layer of diameter "*D*". The fibers are positioned to include nearly uniform spacings "*b*" between adjacent cores. This spacing is sometimes referred to as the inter-fiber distance.

[005] Changes in the inter-fiber distance may affect the light or optical signals propagating along the optical fiber. The wavelength λ of an optical signal changes in the direction of dispersion of the optical signal spectrum in a linear fashion over a short inter-fiber distance "*b*". As such, $d\lambda/dx$ describes the rate of change of wavelength with distance relative to a focal plane of the optical fibers. The ratio of channel spectral width (bandwidth) $\Delta\lambda$ to channel spectral spacing $\Delta\lambda'$ is known as the fill factor, F, and is given by the equation:

$$F = \Delta\lambda / \Delta\lambda' \tag{1}$$

[006] Considering a narrow line in the vicinity of the x-axis (i.e., ignoring the circular shape of the fiber core), and assuming that the image of the input fiber core is no larger than the diameter of the output fiber core leads to:

$$\Delta\lambda / \Delta\lambda' \cong a / b \tag{2}$$

where $\Delta\lambda$ is the full width at half-maximum (3 dB width).

[007] This equation is an approximation, since, if the image of the input fiber is equal in size to the core of the output fiber, aberrations and diffraction will have an effect. Thus, the fill factor may be reasonably approximated by:

$$F = \frac{a}{b} \tag{3}$$

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[008] For some typical single mode fibers, the value of a is approximately 10.4 μm for an optical signal having a wavelength (λ) of approximately 1.55 μm. For many single mode fibers the cladding diameter (D) is approximately 125 μm which means that b is usually no smaller than about 150 μm. The resulting fill factor would be approximately:

$$F = \frac{10.4\mu\,\mathrm{m}}{150\mu\,\mathrm{m}} \equiv 6.9\% \qquad (4)$$

As such, single mode fibers may exhibit low fill factors for given wavelengths, resulting in poor utilization of bandwidth.

[009] The fill factor limitations of existing single mode fibers result in inefficient wavelength-division multiplexers and de-multiplexers, collectively termed wavelength-division modules. As is known, a multiplexer enables multiple carrier waves to be carried on a single transmission medium. In the case of optical networks, a multiplexer receives as input multiple signals operating at different frequencies and separated by some predetermined amount of frequency separation known as the channel spacing. This spacing is usually on the order of 25-200 GHz for multiplexers currently in production. The multiplexer combines these separate signals onto a single optical fiber so that the signals can be transmitted to a remote location. The de-multiplexer works in an opposite fashion, wherein the de-multiplexer separates polychromatic signals into a series of nearly monochromatic signals within narrow-bandwidth channels using a diffraction grating or other optical component(s). Each channel includes a center wavelength derived from the original optical signal.

[010] With existing technologies, the core portion of the optical fibers is usually no more than 10 μm across. Having such a small aperture often requires expensive and time

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consuming alignment procedures to ensure that optical signals are focused onto the fiber core. All of the optical components must be very carefully fixed in place in order to achieve optical alignment and corresponding functionality of the optical device.

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BRIEF SUMMARY OF THE INVENTION

[011] In accordance with teachings of the present invention, an optical system such as a wavelength division multiplexer (WDM) or demultiplexer (WDDM) for communicating optical signals is disclosed. The system includes at least a first optical fiber and a second optical fiber having end portions with expanded core diameters. These expanded core diameters enable less complicated alignment of the optical components of the wavelength division module.

[012] In one configuration, the system includes a lens optically coupled to the end portion of the first optical fiber and operable to communicate optical signals. The end portion of the second optical fiber may be optically coupled to the end portion of the first optical fiber at a distance operable to maintain a fill factor for a wavelength associated with the optical signals. The system may also include a grating optically coupled to the lens and the respective end portions of the first and second optical fibers.

[013] In accordance with one aspect of the present invention, an optical system such as a WDM or WDDM for communicating optical signals is disclosed. The system may include a lens optically coupled to at least one single mode optical fiber including an end portion with expanded core. The system may further include an optical grating or prism optically coupled to the optical lens and operable to communicate optical signals between the end portions of one or more optical fibers. The system may include one or more mounts to position the single mode optical fibers to exhibit an increased fill factor for communicating the optical signals.

[014] In accordance with another aspect of the present invention, disclosed is an optical network that includes a WDM or WDDM for communicating information embodied within an optical signal. The network may include a lens optically coupled to at least two single

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mode optical fibers each of which include end portions with expanded cores. One or more mounts may be provided to position at least two single mode optical fibers to exhibit an increased fill factor for communicating optical signals. The network may further include at least two optical fibers operable to communicate information between an initiating point and a destination point.

[015] In this manner, the present invention provides an optical system exhibiting minimal signal loss through the use of optical transmission mediums that result in increased fill factors for communicating optical signals. The present invention also provides optical systems using tapered core mediums for use with conventional single mode optical fibers for receiving and transmitting optical signals. By using thermally expanded core fibers, an increase in the area of the core is realized. This increased area makes it easier to position and align the optical components, thus saving both time and money in the construction of these components, and overcoming the shortcomings outlined above.

[016] These and other objects and features of the present invention will become more fully apparent from the following description and appended claims, or may be learned by the practice of the invention as set forth hereinafter.

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BRIEF DESCRIPTION OF THE DRAWINGS

[017] A more complete understanding of the present embodiments and advantages thereof may be acquired by referring to the following description taken in conjunction with the accompanying drawings, in which like reference numbers indicate like features, and wherein:

[018] Figure 1 illustrates a prior art parallel arrangement of two conventional single mode fibers;

[019] Figure 2 illustrates one embodiment of a wavelength division demultiplexer and multiplexer (WDDM) using an expanded core optical fiber according to one aspect of the present invention;

[020] Figure 3 illustrates one embodiment of a tapered core optical fiber according to one aspect of the present invention;

[021] Figure 4 illustrates another embodiment of a wavelength division demultiplexer (WDDM) module employing tapered core single mode optical fibers according to an alternate aspect of the present invention.

[022] Figure 5 illustrates an optical network using expanded core optical fibers in WDM and WDDM applications according to the present invention.

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DETAILED DESCRIPTION OF THE EXEMPLARY EMBODIMENTS

[023] Generally, the present invention relates to increasing fill factors for single mode optical fibers used to communicate multiple wavelength optical signals. The present invention will be described in the context of an optical system, such as a wavelength division multiplexer (WDM) or demultiplexer (WDDM). As described above, a multiplexer enables multiple carrier waves, each separated by between about 25-200 GHz channel spacings, to be carried on a single transmission medium. The multiplexer combines these separate signals onto a single optical fiber so that the signals can be transmitted to a remote location. Although reference is made to a specific spacing range, one skilled in the art will understand that other spacing ranges are appropriate.

[024] A WDDM operates in combination with the WDM. The WDDM is, however, typically located at a location remote from the corresponding WDM and de-multiplexes the combined optical signal. More specifically, the WDDM separates polychromatic signals into a series of nearly monochromatic signals within narrow-bandwidth channels using a diffraction grating or other optical component(s). Each channel includes a center wavelength derived from the original optical signal. In this manner, multiple wavelength signals may be communicated from one optical fiber to multiple optical fibers.

[025] Operating characteristics of these WDM's or WDDM's are improved through providing optical fibers having increased relative core diameters for increasing fill factors. The core of these optical fibers has an end portion having a greater diameter than the diameter of the majority of the remaining core of the optical fiber. This expanded end portion of the core allows a greater bandwidth of optical signals to be delivered to the optical fiber and propagated therethrough. As such, a relative decrease in spectral spacing for plural optical fibers may be realized while providing increased fill factors for each

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optical fiber. Further, the increased core diameter reduces the complexity for positioning and aligning the optical fiber in relationship to the remainder of the WDM or WDDM.

[026] Reference will now be made to Figures 2-5 to describe exemplary configurations of the present invention. It is to be understood that the drawings are diagrammatic and schematic representations of presently illustrated embodiments, and are not limiting of the present invention, nor are they necessarily drawn to scale.

[027] Figure 2 illustrates one embodiment an optical system using an expanded core optical fiber according to teachings of the present invention. The optical system may be realized as a WDM or WDDM and is illustrated generally at 200. In the illustrative configuration, system 200 includes a diffraction grating 206 optically coupled to a first lens 204 and a second lens 208. Although reference is made to the WDM or WDDM using a diffraction grating, one skilled in the art will appreciate that WDMs and WDDMs may utilize other optical components to separate or combine one or more optical signals. For instance, other prisms, lenses, gratings, optical thin film filter, etc may be used to separate or combine optical signals.

[028] The first lens 204 is positioned within an optical path between an input fiber 202 and grating 206. The second lens 208 is optically coupled to diffraction grating 206 and directs electromagnetic radiation or light incident on second lens 208 to first output fiber 212 and second output fiber 214. The lenses 204 and 208 may have various configurations so long as they function to direct electromagnetic radiation or light toward diffraction grating 206 or focus electromagnetic radiation or light received from diffraction grating 206 upon focal plane 210 for each respective output fiber 212 and 214.

[029] The ends of first output fiber 212 and second output fiber 214 are maintained within a focal plane 210. This may be achieved by a mount 216, such as a transmitter

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package or module, receiver package or module, a transceiver package or module, or other optical package or module that may receive one or more optical fibers, as known to those skilled in the art.

[030] During use, first lens 204 collimates the electromagnetic radiation or light from input fiber 202 and communicates the same to grating 206. As a WDDM, grating 206 separates the electromagnetic radiation or light into separate optical signals or channels having constituent wavelengths and sends an angularly dispersed spectrum to second lens 208. Second lens 208 focuses a respective linearly dispersed spectrum onto focal plane 210, with first and second output fibers 212 and 214 each receiving a different portion of the spectrum (i.e. a separate channel). For example, first fiber 212 and second fiber 214 receive selected portions of a multiple wavelength optical signal transmitted from input fiber 204.

[031] First output fiber 212 and second output fiber 214 may include single mode fibers including end portions having an expanded core. For example, the single mode fiber may include an end portion having a tapered thermally expanded core (TEC) that increases fill factors relative to single mode fibers having non-expanded cores. Stated another way, the ends of fibers 212 and 214 include the tapered TEC end portion that allows a greater bandwidth of electromagnetic radiation to be received by the respective fiber and enables simple aligning and positioning of fibers 212 and 214 than compared against existing non-expanded optical fibers. As such, efficient communication of optical signals may be realized by increasing the fill factor for systems employing single mode fibers with expanded cores.

[032] Figure 3 illustrates one embodiment of an expanded core optical fiber formed in accordance with teachings of the present invention. The portion of optical fiber 300 shown in Figure 3 includes core 302 and cladding layer 304. Core 302 may include first portion

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306, second portion 308, and third portion 310 formed in accordance with teachings of the present invention. First portion 306 has a diameter 312 corresponding with a typical single mode optical fiber. Third portion 310 may have a diameter 303 which is substantially larger than diameter 312. Second portion 308 may include a tapered configuration, with the diameter of second portion 308 adjacent first portion 306 being substantially similar to the diameter of first portion 306 and the diameter of second portion 308 adjacent third portion 310 being substantially similar to the diameter of first portion 310.

[033] In one embodiment, optical fiber 300 may be a single mode optical fiber with first portion 306 including an optical fiber diameter 312 of approximately 9.5 micrometers and third portion 310 including a diameter 303 of approximately forty micrometers. During use, an optical signal may be communicated via optical fiber 300 using an end portion with an expanded core as part of third portion 310 such that a desired fill ratio may be realized. For example, two single mode optical fibers (not expressly show) may include end portions having expanded cores of approximately forty micrometers and positioned with a spacing of one hundred and fifty micrometers between each fiber. As such, a fill factor of greater than approximately twenty percent may be realized given F = 40/150 is approximately 26.7% from equation (3) above. This is a four-fold increase in the fill factor associated with the WDM or WDDM system of the present invention.

[034] Although reference is made to specific diameters of the core of the optical fiber and the distance between adjacent optical fibers, one skilled in the art may understand that various diameters and distances may be possible to achieve the desired fill factor. For instance, the diameter of the core may range from about 8 micrometer to about 10 micrometers prior to core expansion, while the distance between adjacent optical fibers or the cores of the optical fibers is usually no smaller than 150 micrometers.

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[035] Figure 4 illustrates one embodiment of an optical system operable as a wavelength division demultiplexer (WDDM) module employing tapered core single mode optical fibers according to teachings of the present invention. A WDDM illustrated generally at 400, includes a diffraction grating 402 coupled to a grating mount 404. Diffraction grating 402 is optically coupled to input fiber 406 via lens assembly 408. A fiber mount, not shown in Figure 4, such as but not limited to a v-groove plate, collimator array, or other fiber mount known to those skilled in the art, maintains input fiber 406, a first output fiber 410, and a second output fiber 412 within a focal plane 414.

[036] In one embodiment, input fiber 406, first output fiber 410, and second output fiber 412 may include single mode optical fibers having expanded cores for communicating optical signals. Each fiber, in this illustrative configuration, may include an end portion, such as third portion 310 (Figure 3), with a core diameter of approximately forty micrometers, with adjacent fibers being spaced about 150 micrometers apart. Other embodiments of the present invention may include optical fibers having a core diameter of between about 8 μm to about 10 μm prior to core expansion. Further, the optical fibers may be typically spaced apart at about 150 μm.

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[037] The optical signals communicated from input fiber 406 to grating 402 may be separated into associated spectral components and communicated to each respective output fiber. In this manner, reduced spacings between each fiber and shorter wavelengths for each associated fiber may be realized. Additionally, a decrease in noise or crosstalk between fibers 406, 410, and 412 may be realized in response to providing an increased fill factor for single mode fibers used within WDDM 400.

[038] Figure 5 illustrates a communications network operable to communicate signals using optical modules employing expanded core optical fibers according to teachings of the

present invention. The network, illustrated generally at 500, may be realized in whole or in part, as several types of communications networks that may include wide area networks, interstate or regional networks, local area networks or other networks using optical devices or systems employing single mode TEC fibers for communicating optical signals. Network 500 includes a WDM 502 operable to multiplex signals from sources A-N. Optical signals may be multiplexed and communicated via optical fiber 504 to WDDM 506 operable to demultiplex optical signals. Upon WDDM 506 demultiplexing optical signals, each demultiplexed signal may be communicated to a respective destination such as destinations A-N.

[039] During use, optical signals may be communicated between initiating and destination points using one or more optical components employing optical systems having optical fibers with expanded cores or increased relative core diameters. By employing optical fibers having expanded optical cores, increased fill factors may be realized. As such, network 500 employing devices, systems, components, etc. with expanded core optical fibers may realize a reduction in signal loss resulting in increased efficiency for communicating information via network 500.

[040] Additionally, other optical components employing fibers and single mode fibers with expanded cores or optically increased core diameters may be used within network 500. For example, an optical switch or optical filters (not expressly show) may benefit from using single mode optical fibers or expansion modules, and/or optical lenses having increased relative cores for communicating optical signals. An electro-optic or thermo-optic switch may employ optical fibers having expanded cores for efficiently communicating optical signals while reducing undesirable noise attributed to using optical fibers having low relative fill factors.

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[041] The present invention may be embodied in other specific forms without departing from its spirit or essential characteristics. The described embodiments are to be considered in all respects only as illustrative and not restrictive. The scope of the invention is, therefore, indicated by the appended claims rather than by the foregoing description. All changes that come within the meaning and range of equivalency of the claims are to be embraced within their scope.

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